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## (54) Radio receiver and transmitter providing diversity

(57) A radio receiver is provided comprising first (10) and second (11) antennas, physically spaced apart to provide diversity and an equalizer (20) for combining components of a received symbol which are separated in time. The signals received at the first and second antennas are combined in a combiner (19) and coupled to the equalizer. Delay means (18) are provided in the receive path of one of the antennas, for delaying signals received at that antenna with respect to signals received at the other antenna whereby the probability of destructive interference between the signals from the first and second antennas is significantly reduced. In accordance with a second aspect of the invention, a similar arrangement is provided for diversity in transmission.

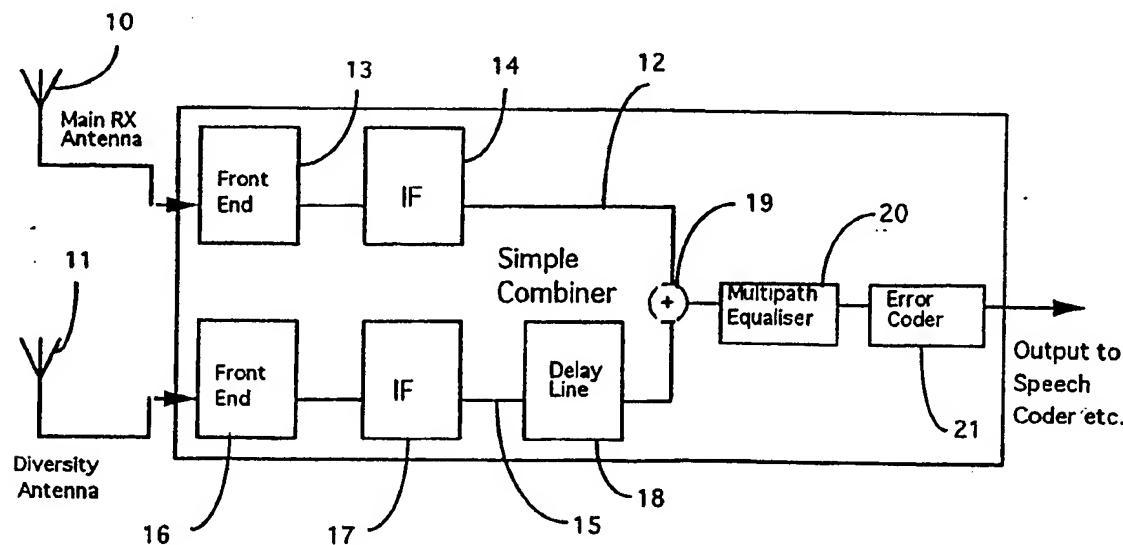


Fig 1

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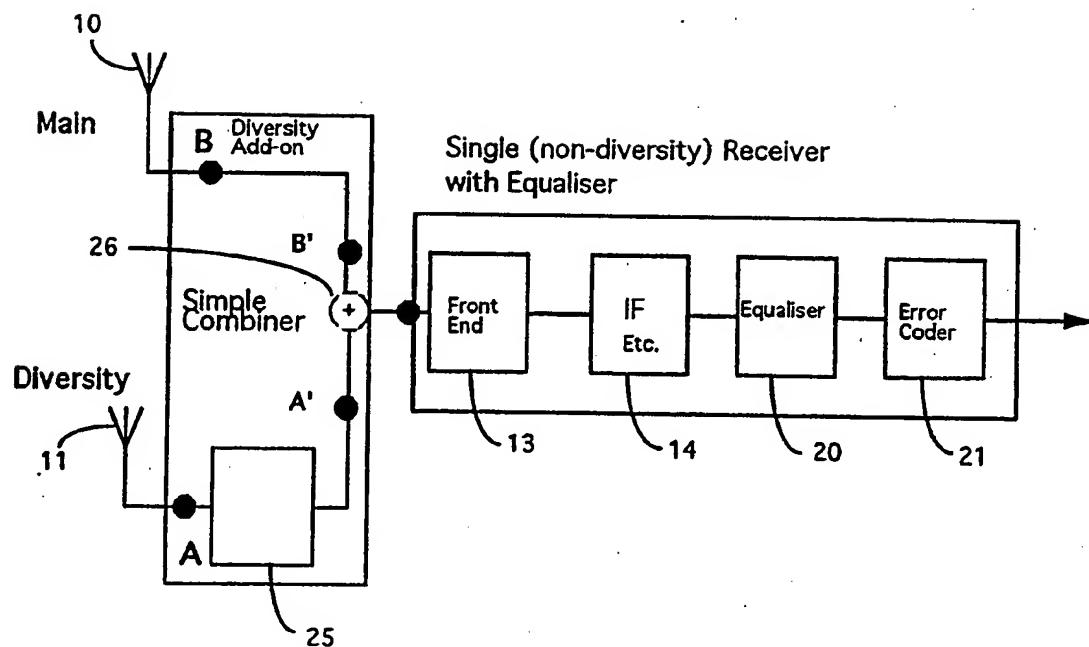


Fig. 3

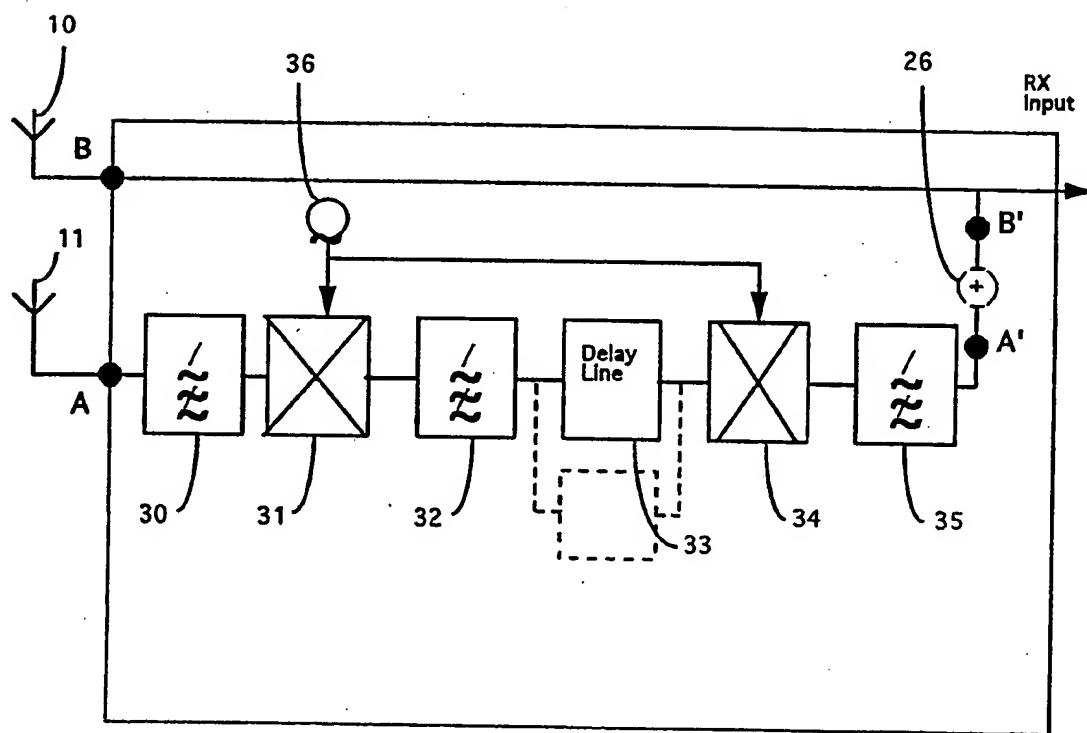


Fig. 4

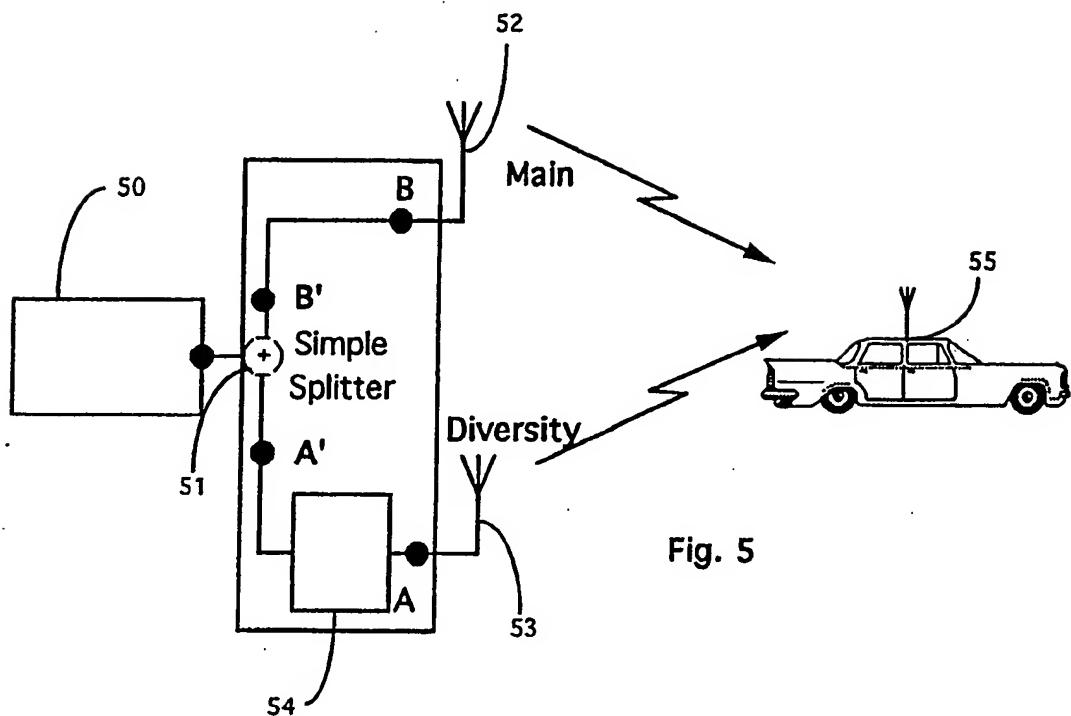


Fig. 5

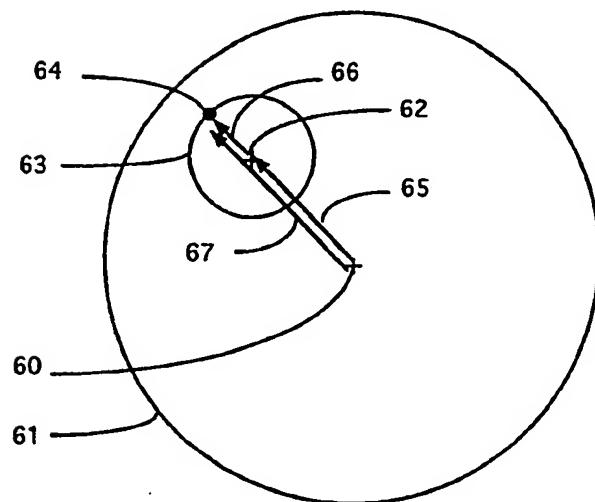


Fig. 6

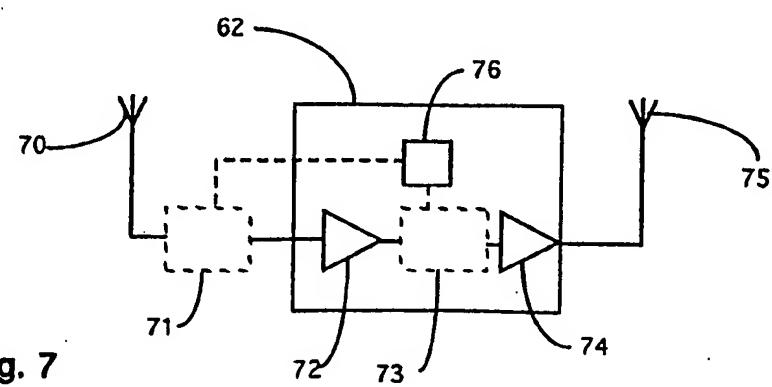


Fig. 7

**RADIO RECEIVER AND TRANSMITTER PROVIDING DIVERSITY****Background of the Invention**

5        This invention concerns a radio receiver providing diversity, otherwise known as "Space Diversity" or "Antenna Diversity". It is, for example, applicable to radio transmission systems which use digital modulation and which incorporate equalizers for the reduction of multi-path propagation effects. An example of such a  
10      system is the GSM digital mobile radio telephone system. The invention also concerns a radio transmitter providing diversity.

**Summary of the Prior Art**

15      Antenna diversity is a technique whereby two receiving antennas are used which are physically spaced apart by several wavelengths. The radio receiver conventionally has two separate parallel amplifying paths to which each antenna is connected. Towards the end of the receiver processing chain the two signals are  
20      fed into a processor which conventionally either selects the best signal or phase shifts and then coherently adds the two signals. The purpose is that for fading signals (e.g. for mobile radio systems), the signals on the two antennas are statistically much less likely to be in a faded condition simultaneously. Thus the diversity combined  
25      signal will exhibit reduced fading effects. The conventional double receiver and diversity combiner add significant extra complexity, however, and it would be desirable to provide a simpler solution.

For digitally modulated radio systems incorporating multi-path equalizers (e.g. GSM), EP-A-0430481 describes a diversity arrangement in which each of two parallel receiver chains is connected to one of two ports of a special two-port equalizer, which acts as an integrated equalizer/diversity combiner. The arrangement nevertheless it still requires a double receiver chain.

Summary of the Invention

In accordance with a first aspect of the present invention, a radio receiver is provided comprising first and second antennas, physically spaced apart to provide diversity, and an equalizer for combining components of a received symbol which are separated in time, characterized in that a combiner is provided for combining the signals received at the first and second antennas and coupling the combined signal to the equalizer and in that delay means are provided in the receive path of one of the antennas, for delaying signals received at that antenna with respect to signals received at the other antenna, so as to significantly reduce the probability of destructive interference between the signals from the first and second antennas.

5 10

In accordance with a second aspect of the invention, a radio transmitter is provided for communication with a receiver having an equalizer for combining components of a received symbol which are separated in time, characterized in that the transmitter comprises first and second antennas, physically spaced apart to provide diversity, splitter means for splitting a signal to be transmitted and coupling it to the first and second antennas and delay means provided in the transmit path of one of the antennas, for delaying signals transmitted by that antenna by more than the predetermined minimum delay with respect to signals transmitted by the other antenna so as to significantly reduce the probability of destructive interference between the signals from the first and second antennas.

15 20 25

The invention provides a very cheap and simple arrangement in which diversity can be provided. A particular advantage is that diversity can be provided by simply adding a combiner, a delay element and an extra antenna, for example in the RF stage. No additional processing is essential, because the signals from the two antennas are additionally combined by the equalizer operating in its normal manner.

30

Two antenna signals may be processed by (different) delay line means or a plurality of antenna and delay lines may be used.

35 Multi-path diversity can be provided through more than two antennas, provided that the signals from the antennas are separated from each other by a delay.

The delay means may be analog or digital and may exist in the IF or RF stages. In the case of RF processing, the delay means can be in the form of an external unit which may incorporate its own frequency converters, IF amplifiers and delay means.

5 The delay between the two or more signals may be varied on a frame-by-frame basis.

The delayed and added signal may be enabled, disabled or modified according to some detected characteristic of the signal, as is described below.

10 In accordance with a third aspect of the invention, a cell enhancer or RF repeater is provided, comprising delay means for delaying signals prior to retransmission, so that the main cell and the repeater signals look like natural multi-path delayed signals where they would otherwise arrive at the receiver simultaneously (e.g. at the cell  
15 enhancer boundary). This minimizes the possibility of destructive interference or fading.

Preferred embodiments of the invention are now described, by way of example only, with reference to the drawings.

## 20 Brief Description of the Drawings

Figure 1 shows a first embodiment of a multi-path enhancement diversity receiver in accordance with the invention.

Figure 2 shows a phasor diagram for explanation of the invention.

25 Figure 3 shows an embodiment of a diversity receiver in accordance with the invention, in which the delay means are provided in the RF stage.

Figure 4 shows an add-on RF diversity unit in accordance with another embodiment of the invention.

30 Figure 5 shows a transmitter providing diversity in accordance with a second aspect of the invention.

Figure 6 illustrates a cell enhancer employing the invention in its second aspect.

35 Figure 7 shows a repeater in accordance with a third aspect of the invention.

## Detailed description of the preferred embodiments

Referring to Figure 1, there is shown a part of a typical GSM radio receiver comprising a main receive antenna 10 and a diversity antenna 11. The main antenna 10 provides a signal to a main receive path 12 comprising a front end RF amplifier unit 13 including a frequency converter unit (not shown) and an IF stage 14. A number of frequency converter units and IF stages may be used. The diversity antenna provides a signal to a diversity receive path 15 comprising a front end amplifier unit 16 and an IF stage 17. The diversity receive path 15 also comprises a delay element 18 which may be in the form of a long transmission line, surface acoustic wave delay line, or one or more filters. The output of the IF stage 14 on the main receive path 12 and the delay element 18 on the diversity receive path are combined in a simple combiner 19 and passed to a multi-path equalizer 20. The multi-path equalizer is in accordance with the GSM specification and may, for example, be that described in EP-A-0318685 or EP-A-0343189. The equalizer 20 is in digital form, i.e. the input to the equalizer 20 is an A/D converter. The equalizer uses four-times oversampling. After equalizing, the signal is subjected to error coding in an error coder 21, in accordance with the GSM specification, and the result is passed to a speech decoder for extracting speech information and synthesizing speech. Analog equalizers could equally be used.

The operation of the receiver of Figure 1 is as follows. A GMSK signal (or other binary modulated signal) is received at an antenna 10 from a mobile transmitter. At the same time, a signal is received from the transmitter at antenna 11 via a different path. Each symbol of the signal has a duration of approximately 4 microseconds. The signals received at the antennas are amplified and down-converted in front end units 13 and 16 and IF stages 14 and 17 respectively. The signal from antenna 11 is delayed in delay element 18. The delay element 18 delays the signal by at least a sufficient fraction of a bit period that when combined in the combiner 19, the probability of destructive interference between the signals from the paths 12 and 15 is significantly reduced. The combiner 19 sums the signals and passes the summed combination to the multi-path equalizer 20. The equalizer 20 performs digital-to-analog conversion and applies appropriate delays and phase shifts to different portions of the signal so as to realign the various components of a symbol in time and phase, in a manner known in the art in respect of inter-symbol interference.

equalization. The equalizer 22 acts on the separate components of the signal received on paths 12 and 15 (and any components introduced by actual multipath reflections before reaching the antennas 10 and 11) and corrects the time error and any phase error therebetween. The 5 resultant equalized signal is demodulated to extract the symbols and subjected to error coding in the error coder 21.

To reduce the probability of destructive interference at the combiner 19, a delay of at least 1/4 bit period is preferred (though smaller delays may suffice). 1/2 bit period is considered a useful 10 delay. A limiting factor is the bandwidth of the filters in the signal path after the combiner. In the GSM system, these filters will remove the distinction between two signals separated by less than about one bit period. Accordingly, a particularly preferred delay is in the 1 to 2 bit-period range. The GSM equalizer is typically designed to equalize 15 delays of up to 16 microseconds and in theory a delay of 10-16 microseconds can be used (i.e. up to 5 bit periods), but some benefit will be lost if the signals themselves are subject to multi-path delay. Use of greater oversampling in the equalizer may permit shorter delays.

The principle of operation of the equalizer 20 is further 20 illustrated with reference to Figure 2. The figure shows a time axis with phasors representing multiple signals illustrated rotating in phase around the time axis. The time axis is shown in stereoscopic view so that both the time delays and the phases of the different phasors can be seen. Two symbols Q1 and Q2 are illustrated separated in phase. If 25 these symbols were to be summed, they would provide the result  $Q_1 + Q_2$  illustrated. It can be seen that these symbols can either be summed together or can cancel each other out with equal likelihood. In contrast, the symbols Q3 and Q4 are illustrated which have been separated in time by delay  $d$ . When summing these in summer 19, being wide-band 30 signals, they cannot cancel each other out. The equalizer performs a phase shift on symbol Q4, bringing it into phase with symbol Q3 and delays symbol Q4 so that it coincides with symbol Q3. Thus the two symbols are added and will always provide a larger resultant signal illustrated as Q3 and Q4.

35 The principle is that the multi-path equalizer will coherently combine two or more signals of any phase which arrive at a receiver antenna, provided that they exhibit a different time delay. This is the normal intended function of the equalizer in enhancing signals which

suffer multi-path propagation. In this application, the diversity signal is made to look like a multi-path delayed signal by the added delay line and it is, therefore, coherently combined by the conventional multi-path equalizer. No additional phase correction is required and

5 provided the equalizer has been optimized, the diversity improvement could be a minimum of 3 dB and typically 6 dB for fading signals. The delay line means could be an analog delay line, a digital delay line, an IF delay line or an RF delay line (see below). Transmission line, lumped circuit, surface acoustic wave or digital circuitry can be used

10 (not necessarily exclusively) for the delay line.

In a linear receiver, such as used for the GSM mobile telephone system, the delay line and simple combiner can be implemented at the front end of the RF section of the receiver. This is illustrated in Figure 3. In this figure, elements of Figure 1 have the same reference numerals as in Figure 1. An RF delay line 25 is connected to the diversity antenna 11 and the other end of the delay line is connected to a simple RF combiner 26, together with an RF connector from the main antenna 10. The output of the combiner 26 is passed to the front end unit 13 and other elements as shown. The arrangement is possible

15 because two or more independent signals can be processed by a linear receiver without mutual interference. This means that the double receiver chain can be dispensed with. A conventional non-diversity receiver (with equalizer) can be used with the diversity components (delay line means and simple combiner) contained within a external,

20 add-on unit.

25

The combiner can be a simple signal adder or a hybrid. The delay line can operate at RF frequencies, or the RF diversity unit can incorporate its own frequency converters so that the delay line can operate at an intermediate frequency, as illustrated in Figure 4.

30 Referring to that figure, elements of Figure 3 are shown with the same reference numerals. Between the diversity antenna 11 and the combiner 26 are provided a first RF filter 30, a mixer 31, an IF filter 32, a delay element 33, a second mixer 34 and a second RF filter 35. Coupled with the mixers 31 and 34 is a local oscillator 36. The mixer

35 31 and generator 36 operate to down-convert the signal to an IF frequency such as 100-200MHz. At such a frequency, a cheap and compact delay element 33 can be implemented, for example in the form of a surface acoustic wave filter. The IF frequency is up-

converted in mixer 34 and the operation of the invention is as for the Figure 3 embodiment.

Items 11, 25 and 26 could be supplied as an add-on unit.

Under certain conditions, when one or more of the diversity signals suffers actual multi-path propagation, it will be advantageous to alter the time delay of the delay line for each frame of the digitally modulated signal. This is achieved by using switchable delay elements, for example as shown in dotted outline in Figure 4, where delay element 40 has a longer delay than that of element 33 and is switchable into the IF path in place of element 33. Alternatively, in the embodiment of Figure 3, the delay element 25 could be switched from the diversity receive path to the main receive path - i.e. between points A-A' and B-B'. Combinations of these arrangements could be used.

15 The switching of the delay element is in response to dispersion information taken from the equalizer 20. As an alternative, the switching is repetitive or pseudo-random.

20 In a further embodiment of the invention, a small frequency shift of about 3 to 5 kHz is applied to the diversity signal and/or a phase shift of 0-360° is applied. This feature provides improvements when the signals are Doppler shifted. In the embodiments of Figures 1 and 4, the frequency shift is applied in the IF stage, for example by adjusting the injection frequency from oscillator 36. The frequency shift can be made at the RF level in a manner readily implemented by one skilled 25 in the art. A phase shift is implemented by a variable capacitor/diode network in the RF signal path, or by a series of transmission line phase shift elements. This technique of switching the delay element operates in conjunction with the error coder 21 in a manner similar to the principal of frequency hopping in the GSM art.

30 As for the switching of the delay element, the frequency shift and/or phase shift is varied on a frame-by-frame basis.

35 The delay, frequency shift and/or phase shift can be enabled, disabled or modified according to characteristics of the received signal such as signal strength, interference or delay spread. In this way, an adaptive multi-path enhancement diversity arrangement is provided.

In principle, multi-path enhancement diversity could be used at the receivers at either end of a two-way radio link. For mobile/portable radio telephone systems, it is rarely attractive to have

a second antenna system on the mobile or portable unit (i.e. diversity for the downlink path - base-to-mobile path).

Figure 5 illustrates an arrangement in accordance with the second aspect of the invention in which a delay element is introduced within 5 the transmitter chain enabling the use of two transmitting antennas at the base station to provide downlink diversity, instead of two receiving antennas on the mobile or portable unit.

The arrangement comprises a transmitter 50, a simple splitter 51, a main transmitter antenna 52, a diversity transmitter antenna 53 and 10 a delay element 54 connected between the splitter 51 and the diversity antenna 53. The transmitter 50 communicates with a mobile unit 55 which incorporates a multi-path equalizer. The additional features of delay switching, frequency shifting and/or phase shifting described above can also be applied. In practice, the delay element 54 is 15 preferably included in the transmit path prior to power amplification of the signal and two power amplifiers are provided for amplifying the primary signal and the delayed signal.

The transmitter 50 can be a transmitter only and the mobile unit 55 can be a receiver only, provided with a multi-path equalizer 20 specifically added for the task of equalizing the signals from the main and diversity antennas 52 and 53.

The principal of the invention can be applied to a cell enhacer to overcome problems at the boundary of the cell enhacer arising from natural multiple paths (from the main cell and the enhacer). This is 25 illustrated in Figure 6, in which a main cell transmitter 60 is shown having a transmit radius 61 and, within the main cell transmit radius there is a cell enhacer 62 having a transmit radius 63. The cell enhacer is typically used to cover a problematic area or "hole" in the cell. It has a transmit radius smaller than that of the main cell. The 30 cell enhacer simply retransmits the signal 65 it receives from the main cell transmitter, with shielding provided to prevent it from retransmitting its own signal. At a point 64 on the boundary of the cell enhacer transmit area, the signal 66 from the cell enhacer may arrive almost simultaneously with the signal 67 from the main cell 35 transmitter. In accordance with this aspect of the invention, the cell enhacer introduces a delay in the signal 66. This delay is periodically switched in order to accomodate possible fading at different points on the cell enhacer transmit boundary.

As shown in Figure 7, the cell enhancer 62 comprises a receive antenna 70 a transmit antenna 75 and a receive/transmit path comprising preamplifier 72 and power amplifier 74. A delay element is introduced on the receive side at position 71 or before the power 5 amplifier at position 73. The delay is switched frame-by frame by timing circuitry 76. It will be understood that variations described above in relation to receive diversity and transmit diversity can be implemented. For example there can be more than one receive 10 antenna or more than one transmit antenna. In each case the signal through one antenna is delayed with respect to the signal through the other(s).

## Claims

1. A radio receiver comprising first and second antennas, physically spaced apart to provide diversity;
- 5 an equalizer for combining components of a received symbol which are separated in time, characterized in that a combiner is provided for combining the signals received at the first and second antennas and coupling the combined signal to the equalizer
- 10 and in that delay means are provided in the receive path of one of the antennas, for delaying signals received at that antenna with respect to signals received at the other antenna so as to significantly reduce the probability of destructive interference between the signals from the first and second antennas.
- 15 2. A radio receiver according to claim 1, wherein the delay means are variable.
3. A radio receiver according to claim 2, comprising means for receiving a signal which is divided into discrete frames and means for varying the delay from frame to frame.
- 20 4. A radio receiver according to claim 3, wherein the equalizer comprises means for indicating a characteristic of the received signal and the means for varying the delay varies the delay in response to the characteristic.
- 25 5. A radio receiver according to claim 4, wherein the characteristic is the dispersion of the received signal.
- 30 6. A radio receiver according to any one of the preceding claims wherein the delay means further comprises frequency shift means for shifting the frequency of the signal received at one antenna with respect to the frequency of the signal received at the other antenna.
- 35 7. A radio receiver according to any one of the preceding claims wherein the delay means further comprises phase shift means for

shifting the phase of the signal received at one antenna with respect to the phase of the signal received at the other antenna.

8. A radio receiver according to any one of the preceding claims  
5 wherein the radio includes a radio frequency stage and the delay means are located in that stage.

9. A radio receiver according to any one of claims 1 to 8 wherein  
10 the radio includes an intermediate frequency stage and the delay means are located in that stage.

10. A radio receiver according to any one of the preceding claims, for receiving signals comprising periodic bits, wherein the delay means cause a delay of at least a quarter of a bit period.

15 11. A radio receiver according to any one of the preceding claims, for receiving signals comprising periodic bits, wherein the delay means cause a delay of at least a full bit period.

20 12. A radio receiver add-on unit for use with a radio receiver having an equalizer for combining components of a received symbol which are separated in time, the add-on unit comprising:

a diversity antenna,  
means for coupling to a principal antenna  
25 a combiner, and

delay means coupled between the combiner and one of the diversity antenna and the means for coupling to the principal antenna, for delaying signals received at one antenna with respect to signals received at the other antenna so as to significantly reduce  
30 the probability of destructive interference between the signals from the first and second antennas.

35 13. A radio receiver according to any one of the preceding claims, comprising a primary antenna, a plurality of secondary antennas spaced apart to provide diversity and delay means in the receive path of each secondary antenna, for causing signals received at each secondary antenna to be separated in time by more than a

predetermined minimum delay with respect to signals received at each other antenna.

14. An add-on unit according to claim 12 wherein the delay means 5 comprises down-converter means and up-converter means, wherein the delay means are located between the down-converter means and the up-converter means.

15. A radio receiver or add-on unit according to any one of the 10 preceding claims, wherein the delay means comprise a surface acoustic wave element.

16 A radio transmitter for communication with a receiver having an equalizer for combining components of a received symbol which 15 are separated in time, characterized in that the transmitter comprises first and second antennas, physically spaced apart to provide diversity, splitter means for splitting a signal to be transmitted and coupling it to the first and second antennas and delay means provided in the transmit path of one of the antennas, 20 for delaying signals transmitted by that antenna by more than the predetermined minimum delay with respect to signals transmitted by the other antenna so as to significantly reduce the probability of destructive interference between the signals from the first and second antennas.

25 17. A repeater, for receiving signals from a main transmitter and retransmitting them, comprising delay means for delaying signals prior to retransmission, such as to simulate multi-path spread within the common transmission areas of the main transmitter and the repeater.

## Relevant Technical fields

(i) UK CI (Edition X) H4L (LDDRX, LDDRCX, LDDSX)

(ii) Int CI (Edition 5) H04B 7/04, 06, 08 H04L 1/06

Search Examiner

N W HALL

## Databases (see over)

(i) UK Patent Office

(ii) WPI ONLINE

Date of Search

6 FEBRUARY 1992

## Documents considered relevant following a search in respect of claims

1-15

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 237706 A (RACAL) See figure 3, page 9, line 24 - page 10, line 2	1, 11, 12
X	EP 0333042 A1 (ALCATEL) See figure 1	1, 12
X	US 4972434 (LE POLOZED) See figure 1	1, 2, 12

SF2(p)

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Category	Identity of document and relevant passages	Relevance to claim(s)

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